Self-compacting fibre-reinforced concrete

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The project 'self-compacting fibre-reinforced concrete (SCFRC)' is part of the Dutch STW/PPM program – 'cement-bonded materials' - DCT.4010. Subproject III to which the project ‚SCFRC' belongs deals with the development of new high performance concretes. The project 'SCFRC' aims at investigating the effect of type and content of fibres on the characteristics of self-compacting concrete in order to optimise the mixture composition. Fibres are able to bridge cracks and to improve the ductility of otherwise brittle cementitious materials. Therefore, the addition of fibres might extend the possible fields of application of self-compacting concrete. Besides the properties in the fresh state, while the concrete still flows, the mechanical behaviour will be investigated. This paper aims at introducing the reader to the goals, methods of research, and first experimental results of the project 'SCFRC'.

Key words: **self-compacting concrete, fibres, mix design, mechanical behaviour**

1 Introduction to the project

In 1996, subproject III, which takes part of the Dutch STW/PPM project DCT.4010 - 'cement-bonded materials', was started. Subproject III consists of three related projects: self-compacting concrete (SCC), high performance steel fibre-reinforced concrete (HPSFRC) and self-compacting fibre-reinforced concrete (SCFRC).
The project 'SCC' was set-up to investigate the physical backgrounds of this special type of concrete. SCC flows only due to its own weight, without any vibration into each corner of the formwork without any kind of segregation or blockade. The need to compact normal concrete by the use of vibration has considerable impact on the working conditions, the required labour costs, and sometimes on the quality of concrete. For these reasons, SCC offers interesting perspectives to the building industry.
The project 'HPSFRC' aimed to investigate the effect of steel fibres on the mechanical behaviour of concrete. The result of this study, which has already been completed [Kooiman, 2000], is a reliable material model for both the behaviour of steel fibre-reinforced concrete in tension and bending.
Finally, the project 'SCFRC' was started. Based on the knowledge still available in this group, fibre-reinforced concrete with self-levelling properties should be developed. SCFRC has approved characteristics after mixing compared with plain fibre-reinforced concrete - better homogeneity and self-levelling properties - and shows an improved ductile behaviour compared with plain SCC. The addition of the fibres improves the characteristics of SCC in the hardened state. But fibres are also known to significantly affect the characteristics of concrete in the fresh state. Therefore, the question arises whether the fibres are detrimental to the workability of SCC.

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The effect of type and content of fibres on the workability of SCC has been investigated in an experimental parameter-study. Special attention had to be paid to the mixture composition, which had to be adjusted according to the type and content of the fibres applied. In order to benefit from the project 'SCFRC' and to reduce trial and error on concrete plants, the analysis of the results of the experiments and modelling the behaviour of SCFRC in the fresh and hardened state by use of physical parameters are essential parts of this research project.

2 Self-compacting concrete and fibres-workability contra performance in the hardened state?

Self-compacting concrete

SCC has to have defined characteristics at the moment of casting in order to be able to pass reinforcement, with the weight of the concrete being the only driving force. During casting, the utmost part of the enclosed air should escape. High flowability, stability and the ability to pass reinforcement are the decisive properties. Several approaches for mix design were developed [Okamura and Ouchi, 1999], [Peterson and Billberg, 1999] and [Sedran and De Larrard, 1999].

Japanese researchers [Okamura and Ouchi, 1999] first started to investigate SCC. Their approach was to optimise SCC on different levels: performing paste tests, optimising the mortar, and finally adjusting the concrete.

First, they considered the level of cement paste. Cement and fillers are solid particles at a defined porosity of its granular skeleton. The water fills the interstices of the granular skeleton and lubricates the solids with a thin layer of water. At this first stage, the water demand of the powders has to be determined.

Second, the cement paste lubricates small aggregates in mortar [Fig. 1]. Usually, superplasticizer will be applied in order to reduce the required content of water. The contents of water and superplasticizer have to be adjusted in order to achieve the defined characteristics of mortar, which were determined experimentally.

Finally, the content and maximum size of coarse aggregate have to be chosen to pass the reinforcement at a specified bar spacing. The denser the configuration of reinforcement, the lower the possible content of coarse aggregate.

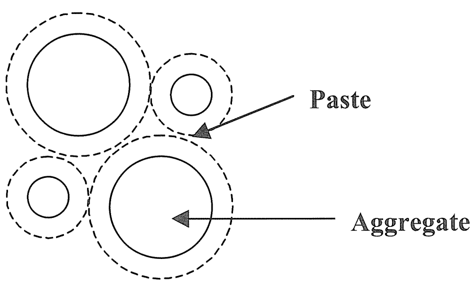


Figure 1. Aggregates surrounded by paste

The porosity of the granular skeleton is of special interest for this approach. The thicker the lubricating layer becomes the easier is the movement of the particles. The denser the granular skeleton, the less paste is required to fill the voids. Then, the concrete would become less expensive because the fine binder materials are usually the most expensive part of concrete. Furthermore, time-dependent deformations, which are caused by shrinkage or swelling of the cement paste would be less pronounced.

Fibres and workability
Fibres are produced in a wide range of materials, at different shapes, with divergent properties concerning their affinity to paste or water. Some types of fibres are fragile, flexible or stiff, cylindrical, rectangular or irregularly shaped. They are known to affect the workability and the flow characteristics essentially. Fibres have a long shape and compared with aggregate of the same volume a higher specific surface. Longer fibres at smaller diameters are more efficient in the hardened state; the workability is even more affected. Therefore, a compromise between improved performance in the hardened state and acceptable properties in the fresh state has to be made. Furthermore, long fibres tend to entangle and to build 'nests' of fibres. A stiff internal structure counteracts the flow.

A mixture of randomly distributed fibres has a high porosity. The larger the ratio between the aggregate size and the length of the fibres becomes, the higher the porosity of the granular skeleton. Aggregates are not single-sized in concrete; a range of sizes, in most cases from 0.125 mm up to 16 or 32 mm has been applied. To compensate for the effect of the fibres, more fines should be added to fill the additional interstices between the aggregates (Fig. 2). It seems reasonable to adjust the mixture composition compared to concrete without fibres depending on the type and content of fibres applied.

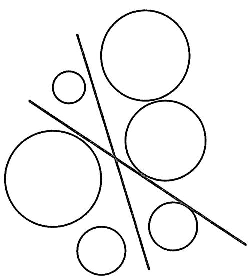


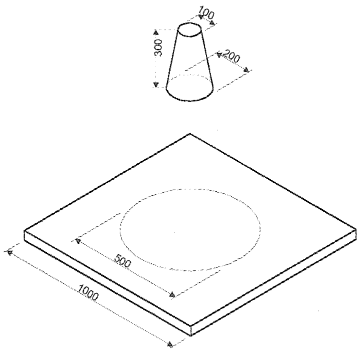
Figure 2. Fibres and aggregates as granular skeleton

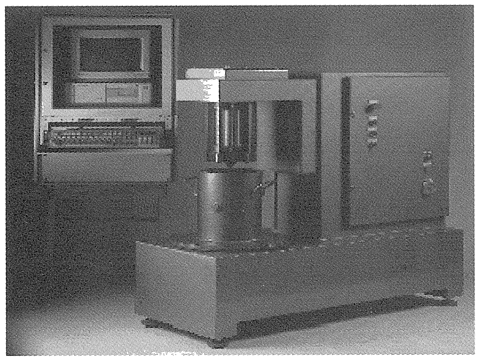
3 Experimental approach and results

The research project 'SCFRC' aims at investigating mixtures with various maximum aggregate sizes from 1 up to 16 mm. An extensive parameter-study has been carried out as a part of the program; several types of flowing mixtures were developed for laboratory and practical purposes. Besides the characteristics in the fresh state, the mechanical properties have been addressed.

Characteristics in the fresh state

Plain SCC needs to have a specified performance at the moment of casting. The same criteria have to be applied for SCFRC. In order to explain the response of the concrete on a macro-level, the characteristics of the granular skeleton and the rheological properties of the cement paste have to be considered on a lower level. The rheological properties of SCC have been measured; empirical tests, like the measurement of the slump flow and more sophisticated methods, testing concrete and paste by the use of rotational viscometers were applied. Fig. 3 shows the test set-up used to measure the flow spread [dimensions cone according NEN 6722]. Fig. 4 shows the BML-viscometer, a rotational viscometer for coarse particle suspensions that has been applied to measure the rheological characteristics of the concrete.





Figures. 3 and 4. Measuring the slump flow (left); BML-viscometer (right)

Several series of concrete mixtures were studied in order to find the effect of type and content of fibres on the workability of SCC. The aim of this study is to determine the maximum fibre content and the decrease of workability and mechanisms of interaction due to the action of the fibres. Four SCC mixtures at defined characteristics, at a high flowability and still sufficient stability to avoid segregation and bleeding, were developed. Fig. 5 shows different contents of cement paste and coarse aggregate of four series of SCC at a maximum aggregate size of 16 mm.

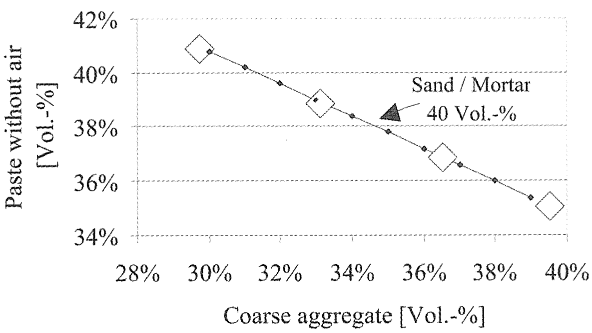


Figure 5. Four series SCC at different mixture compositions

Series 1 was the SCC with the highest content of coarse aggregate and the lowest content of paste. The number of the series increases with increasing paste content. The content of air was 2.0 Vol.-%. The slump flow test [Fig. 3] was applied to characterise the flowability. All reference mixtures were adjusted to achieve a flow spread of about 700 mm, a value that seems to be rather arbitrary; in fact, this value was experienced as an upper limit of flowability. Concrete mixtures at larger diameters are prone to static segregation of the concrete. Different types and contents of steel fibres were added to study their effect on the characteristics in the fresh state. Fig. 6 shows how the flow spread decreases with increasing fibre factor. The fibre factor is the product of the content of steel fibres in the concrete and the aspect ratio of the steel fibres [Vf ·L/D]. This factor was applied to compare the results of mixtures at various types and contents of steel fibres [Groth and Nemegeer, 1999]. The mixtures of series 1 show a steeper slope than the mixtures of series 2 to 4; the diameter of the flow spread was more affected due to the addition of the fibres.

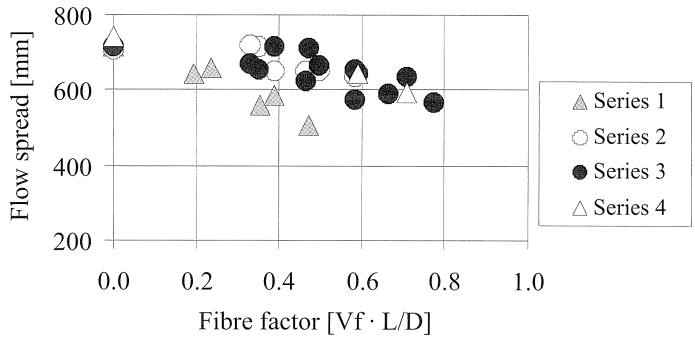


Figure 6. Effect of the fibre factor on the size of the flow spread

Characteristics in the hardened state

The benefit from the fibres is twofold: They arrest internal micro-cracks and increase the strength of the matrix and, if a crack occurs, the fibres are still able to transmit loads across a crack [Rossi et al., 1987]. Steel fibre-reinforced cementitious materials are more ductile than plain concrete without fibres. Fig. 7 shows the test set-up of the three-point bending test that was applied at the Delft University of Technology [Kooiman, 2000].

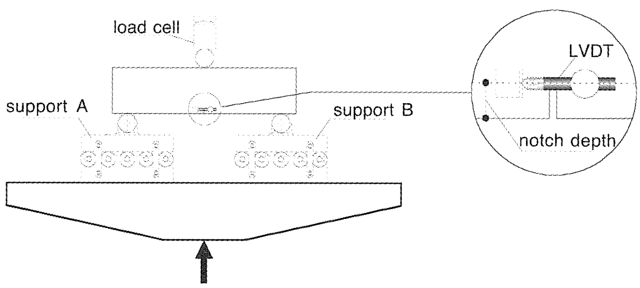


Figure 7. Three-point bending test

The three-point bending test according to RILEM TC 162-TDF was proposed to evaluate the behaviour of steel fibre-reinforced concrete in tension in terms of areas under the load-deflection curve by testing single notched beams. During the flow the fibres tend to orient along with the flow [Groth and Nemegeer, 1999] thereby reducing the internal resistance to flow. In this way, the efficiency of the fibres in one direction could be increased without any increase of the costs. The test result will depend on the manner the test specimens are cast.

4 Summary

This paper gives an introduction to the research project 'SCFRC'. After a brief review of the problems concerning this research project and the methods applied, first results were presented. The project 'SCFRC' aims at investigating the effect of type and content of fibres on the characteristics of this new type of concrete in the fresh and hardened state.

At this stage of the project, we are able to compose SCFRC at defined properties. Additional experimental studies will be carried out, while varying the most important parameters. Analysing the results of the experiments and modelling the behaviour of SCFRC in the fresh and hardened state are essential parts of the study. This project aims at providing physical insight in mechanisms that govern the flow, and to offer a guideline to compose SCFRC with defined charactemistics for practical purposes.

5 References

Groth, P., Nemegeer, D., The use of steel fibres in self-compacting concrete, in: Å. Skarendahl, Ö. Petersson, (Eds.), Self-Compacting Concrete, RILEM Symposium Stockholm, RILEM publications, Cachan, 1999, pp. 497-507.

Kooiman, A.G., Modelling Steel Fibre Reinforced Concrete for Structural Design, PhD-thesis, Section of Concrete Structures, Delft University of Technology, 2000.

NEN 6722, Code for Concrete Technology (VBT 1995). Requirements, production and testing (in Dutch).

Okamura, H., Ouchi, M., Self-compacting concrete, Development, present use and future, in: Å. Skarendahl, Ö. Petersson, (Eds.), Self-Compacting Concrete, RILEM Symposium Stockholm, RILEM publications, Cachan, 1999, pp. 3-14.

Petersson, Ö., Billberg, P., Investigation on blocking of self-compacting concrete with different maximum aggregate size and use of viscosity agent instead filler, in: Å. Skarendahl, Ö. Petersson, (Eds.), Self-Compacting Concrete, RILEM Symposium Stockholm, RILEM publications, Cachan, 1999, pp. 333-344.

RILEM TC 162-TDF, Draft Recommendation, Test and design methods for steel fibre reinforced concrete, Bending test, Materials and Structures, Vol. 33, Jan.-Feb. 2000, pp. 3-5.

Rossi, P., Acker, P., Malier Y., Effect of steel fibres at two different stages: the material and the structure, Materials and Structures Vol. 20, 1987, pp. 334-337.

Sedran, T., Larrard, F. de, Optimization of self-compacting concrete thanks to packing model, in: Å. Skarendahl, Ö. Petersson, (Eds.), Self-Compacting Concrete, RILEM Symposium Stockholm, RILEM publications, Cachan, 1999, pp. 321-332.